DOCUMENT RESUME

ED 071 250 40 EC 050 525

AUTHOR	Nober, E. Harris
TITLE	The Development of Audiologic Criteria to Differentiate Between Auditory Thresholds and Cutile Thresholds of Deaf Children. Final Report.
INSTITUTION	Massachusetts Univ., Amherst.
SPONS AGENCY	Bureau of Education for the Handicapped (DHEW/OE), Washington, D.C.
BUREAU NO	BR-8-0321
PUB DATE	Sep 71
GRANT	OEG-0-8-080321-4463(032)
NOTE	103p.
EDRS PRICE	MF-$0.65 HC-$6.58
DESCRIPTORS	Adolescents; *Audiology; *Audition (Physiology); *Auditory Tests; *Aurally Handicapped; Cutaneous Sense; Deaf; *Exceptional Child Research; Testing Problems

ABSTRACT

Researchers investigated a variety of audiologic procedures to determine whether they could differentiate between auditory thresholds and cutile (cutaneous-tactile) thresholds of 32 deaf adolescents. Ss were classified into one of the following three groups: a cutile group with no pure tone thresholds beyond 750 Hertz (Hz); a group of questionable classification with responses at 1000 Hz; and Ss designated partially deaf with elicited thresholds at 2000 Hz or above. The responses of the Ss were statistically analyzed to ascertain if the groups were functionally related or differentiated relative to a number of psychophysical auditory procedures. All Ss were profoundly deaf, had normal intelligence, good emotional stability, and no history of brain damage. Instrumentation included a Beltone 150, Maico M-24, Grason-Stadler Bekesy audiometer, Grason-Stadler speech audiometer, Bruel and Kjar sound level meter, Sony tape recorder, and rubber ear inserts. Numerous tests were administered including tests of pure tone air conduction thresholds, pure tone bone conduction thresholds, mastoid versus forehead bone conduction, and occlusion thresholds. Conclusions were said to support the thesis that audiograms of deaf children could be designated as cutile to indicate a total hearing loss or classified as partially deaf to indicate some auditory reserve. (GW)

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THE DEVELOPMENT OF AUDIOLOGIC CRITERIA TO DIFFERENTIATE BETWEEN AUDITORY THRESHOLDS AND CUTILE THRESHOLDS OF DEAF CHILDREN

E. Harris Nober
Syracuse University
Syracuse, New York

University of Massachusetts
Amherst, Massachusetts

September, 1971

Department of Health, Education and Welfare
U. S. Office of Education
Bureau of Education for the Handicapped

FINAL REPORT

Project No. 8-0321

Grant No. OEG-0-8-080321-4463(032)

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E. Harris Nober

Syracuse University
Syracuse, N.Y.
(Initiated and implemented)

University of Massachusetts
Amherst, Mass. 01002
(Completed)

September, 1971

The research reported herein was performed pursuant to a grant with the Bureau of Education for the Handicapped, U.S. Office of Education, Department of Health, Education, and Welfare. Contractors undertaking such projects under government sponsorship are encouraged to express freely their professional judgment in the conduct of the project. Points of view or opinions stated do not, therefore, necessarily represent official position of the Bureau of Education for the Handicapped.

Department of Health, Education and Welfare
U.S. Office of Education
Bureau of Education for the Handicapped

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I. SUMMARY

During the past decade, there has been an impressive number of studies which suggested that the air and bone audiograms of deaf children may not reflect true auditory reserve, but were vibrotactile exteroception. These ostensible hearing thresholds are elicited at high intensity levels, contiguous to the maximum output on the audiometer. Originally, the maximum output limits were based on the psychophysiologic sensory substrates of "feeling", "tickle" or "discomfort" for normal hearing subjects. However, there is no reason to assume that the deaf have comparable non-auditory psychophysiologic sensations to an intense sound. A non-hearing deaf child is devoid of the intrinsic protection afforded by the hearing mechanism and subsequently may detect the low frequency air and bone vibratory sensations at even lower thresholds than the normal hearing who has the confounding effects of a modality competition. Skin sensitivity peaks to vibrotactile sensations around 250 Hz where the deaf conspicuously give nearly universal responses to intense sound stimulation.

So impressive is this mounting array of evidence that Nober (1969, 1970) has designated these predictable and reliable <u>cutan</u>eous-tact<u>ile</u> thresholds as <u>cutile</u> to specify the modalities that mediate the sensations. This term avoids the undesirable and negative connotation associated with describing what the elicited responses are not; i.e. invalid, pseudoauditory, vibrotactile, etc. Nober (1969) demonstrated that certain ostensible auditory air conduction thresholds were not true auditory thresholds. He conjectured cutile thresholds should be extinguished with a local

subcutaneous xylocaine block while auditory thresholds should be unaffected by the anesthesia and prevail during the sensory block. Indeed, this author extinguished the cutile air conduction thresholds from the "totally deaf" cutile subjects with anesthesia while the "partially deaf" subjects with some auditory reserve maintained their air conduction thresholds.

Although several isolated audiologic procedures were described to identify the cutile thresholds, no formal study of audiologic procedures has been launched to determine if the cutile subjects could be audiologically differentiated from the partially deaf with auditory reserve. Thus, a comprehensive psychophysical assessment of the auditory function of deaf children has not been systematically studied with the delineation of cutile and partial deafness.

The constant improvements of electronic hearing aids and auditory training devices have augmented an emphasis on auditory training programs for classroom teaching and habilitation. Serious question arises whether the children who continuously fail to benefit from the auditory approach constitute the non-hearing cutile group. If this is the case, then reconsideration of the accelerated impetus of auditory habilitation is appropriate; perhaps, more efficient compensations from adjunct modalities are worth exploring and implementing.

It was not within the scope of this current study to explore the habilitative effects of different transducers, varieties of frequency transportation, etc., but the implications for future exploration are worth noting. This study investigated the audiologic functions of deaf children with the current armamentarium of audiologic procedures and innovated modifications and new procedures when warranted. Controversy exists concerning whether the nonhearing cutile group actually detect air and bone conduction tones at 1000 Hz or whether the upper vibrotactile limit is 750 Hz. To explore this controversial issue further, the experimental subjects or their ears were categorized into three groups:

1. Group A represented the cutile group with no pure tone thresholds beyond 750 Hz;
2. Group B was the questionable category with responses at 1000 Hz;
3. Group C designated the partially deaf subjects with elicited thresholds at 2000 Hz or above.

The responses of the subjects grouped in these three audiogram categories were statistically analyzed to ascertain if the groups were functionally related or differentiated relative to a number of psychophysical auditory procedures. In several instances, all three group scores were pooled for a total deaf contingent evaluation.

There were two ways of classifying the data into groups A, B, or C as determined by conventional audiometry. One designation classified the individual per se into one of the three groups based on the audiogram of the better ear and the other classification designated each ear independently into one of the three categories. The rationale for employing the first or second classification systems depended on the nature of the test. In the first classification with the individual placed into one category, the better ear was the criterion as the functional integrity of the better ear correlates with the overall performance of an individual. The second classification assumed psychoacoustic independence between the two ears; a precedented assumption for conducting most conventional hearing test. Thus, with this latter classification, it was possible for both ears to be included in the same category or each ear in a different category. This information was always clearly discussed for each test.

Thirty-two deaf subjects from one school for the deaf comprised the experimental student population. There were 13 girls and 19 boys who ranged in age from 14-17 years, inclusive. All subjects were profoundly deaf, had normal intelligence, good emotional stability and no history of brain damage.

Instrumentation included a Beltone 150, Maico M-24, Grason-Stadler Bekesy audiometer, Grason-Stadler speech audiometer, Bruel and Kjar sound level meter, Sony tape recorder, rubber ear inserts and other miscellaneous items. The following audiologic tests were conducted with this equipment:

1. pure tone air conduction thresholds.
2. pure tone bone conduction thresholds.
3. mastoid vs. forehead bone conduction.
4. occlusion thresholds.
5. Bekesy audiograms.
6. intensitive difference-limen (modified SISI).
7. localization in a minimum-audible field.
8. monofrequency and bifrequency identification in a minimum-audible field.
9. tone decay scores.
10. speech reception thresholds.
11. discrimination scores.

All data were transformed to fortran sheets and put on tape for statistical analysis. This data were summarized into mean values and categorized into the three deaf groups. In several tests, the skewed data were subjected to arcsin transformations and the analyses conducted on the arcsin data.

Bekesy air conduction thresholds were analyzed with analysis of variance and *t* tests. As bone conduction data were constricted to a narrow range, they did not lend to conventional statistical analyses.

Intensitive difference-limen percentage values were subjected to arcsin transformation and analyzed with analysis of variance. In several instances, matched t-tests explored the differences between specific means. One-way analyses of variance were used for analyzing the localization scores and the monofrequency-bifrequency scores.

The results were as follows:

1. Conventional pure tone air and bone conduction thresholds showed statistical differences for the variables of groups, intensity and method of presentation.
2. In many instances, the cutile group was audiologically differentiated with the air and bone conduction from the other two groups with statistical significance. Generally, the air conduction thresholds of the cutile group were higher than the other two groups.
3. There was evidence that thresholds elicited with air and bone conduction at 1000 Hz represented true auditory responses.

4. Left and right ears were nearly universally identical throughout the study, regardless of the parameter or test procedure.

5. Frontal vs mastoid placements of the bone oscillator precipitated higher thresholds with the former; there were no demonstrable group differences.

6. Generally, bone conduction procedures such as the occlusion effect did not differentiate among the groups.

7. Bekesy audiometry yielded results consistent with the conventional air conduction data.

8. Bekesy Type I configurations were nearly universal as the continuous and interrupted tracings were intertwined throughout, regardless of the parameter.

9. Bekesy audiometry differentiated the cutile from the partially hearing deaf.

10. Intensitive difference-limen percentage values differentiated between the cutile and the partially hearing deaf.

11. Intensitive difference-limen percentage values were statistically differentiated with the air and bone conduction methods of presentation, groups and intensity increments.

12. Intensitive difference-limen values showed statistically significant intensitive decrements relative to several variables.

13. Localization in a minimal-audible-field statistically differentiated between the cutile and

the partially deaf groups at 250 Hz and 500 Hz.

14. Monofrequency-bifrequency identification in a minimal-audible-field statistically differentiated between the cutile and the partially hearing deaf groups.

15. Tone decay threshold shifts differentiated among the cutile and the partially hearing groups. While some differences occurred at 250 Hz, the means at 500 Hz reached statistical significance.

16. Tone decay may offer additional diagnostic information in regard to site of lesion.

17. Speech reception thresholds and discrimination scores were extremely poor and did not differentiate among the groups.

Significance and implications.

This study contributed additional evidence that the audiograms of deaf children could be designated as "cutile" to indicate a total hearing loss or classified as "partially deaf" to indicate some auditory reserve. It was possible to demonstrate, with statistical support, that some audiologic procedures differentiated between the auditory and cutile thresholds. These procedures certainly warrant further investigation for refinement and standardization. The results should be construed as reflecting trends until more conclusive and extensive work is completed. In this study, there was a relatively limited sampling of deaf population and comparable studies must be implemented to a wider population representing different schools, age groups and etiologies.

There are several implications of these results for education and therapy. Perhaps new or modified goals should be given to the teachers and the therapists who are involved with the education and habilitation of the deaf. Diagnosticians and therapists would review their orientations as well. Different prosthetic devices might be explored in relation to the cutile and partially deaf delineations. It is reasonable to conjecture that the remedial emphasis on the auditory modality may be less effective with the cutile group. Also, the speech patterns relative to a cutile and hearing dichotomy warrants investigation.

There is a need to investigate, in detail, the implications of the various achievement level trends of the deaf vs the hearing. Similarities and differences have theoretic and pragmatic pertinence. Careful analysis of longitudinal studies should be profitable. These data suggest the teacher of the deaf can expect more difficulties in some learning areas than in others. Some of these are the reverse of the normal hearing patterns. Hence, a teacher who is accustomed to working with normal hearing children would need to be aware of the marked differences and the rationale for these disparaties.

Recommendations.

1. This study should be repeated on a more extensive population, particularly for the significant parameters.
2. Normalization of some of these data is essential if cutile subjects are to be differentiated with audiologic procedures.
3. Programmatic exploration of the effects of training,

amplification, and educational procedures should be studied longitudinally with careful consideration of the cutile and partially hearing classifications.

4. Achievement level patterns should be studied in greater detail and examined for the underlying principles involved.
5. More extensive dissemination to audiologists, language therapists and teachers of the deaf is essential.

II. INTRODUCTION

A. Problem

The purpose of this study was to explore the audiologic function of deaf students and ascertain whether it was possible to differentiate between valid residual hearing thresholds and cutile (cutaneous-tactile) thresholds that reflect a totally deaf ear with no demonstrable auditory sensitivity to sound. Audiograms of partially deaf and totally deaf children are often relatively comparable in magnitude and configuration.

This investigation conducted a conventional and improvised audiologic battery of tests on deaf children to determine whether an audiologic pattern can be gleaned to differentiate between auditory thresholds and cutile thresholds. Several of the "improvised" tests provided basic sensation and perception relative to specified psychophysical techniques.

B. Background

In a previous study, Nober (1969, USOE Grant 1-7-063073-2198) obtained air and bone conduction thresholds on deaf and normal hearing subjects before and during the elimination of cutaneous and tactile interference with anesthesia.

Twenty-one subjects were grouped into five "priority deaf" (totally deaf), six "control deaf" (residual hearing), and ten "normal" hearing subjects. Each subject was tested on several occasions for air and bone conduction thresholds and finally given a local subcutaneous injection of 2% xylocaine to eliminate local cutaneous-tactile exteroception interference. Results were quite definitive. Only the air conduction thresholds for the totally deaf subjects were extinguished by the anesthetic block. The air conduction thresholds of the partially deaf and the normal hearing subjects did not extinguish during the anesthetic block. There were a few minor isolated departures that occurred for some of the control deaf subjects but without regularity. Bone conduction thresholds remained stable for all three groups as the local subcutaneous block was too peripherally restricted for the diffuse bone propagation that occurs with high intensity output levels.

Nober (1969) concluded that the air and bone conduction thresholds for many profoundly deaf children were not auditory but mediated through the cutaneous-tactile receptors and, subsequently, he coined the term <u>cutile</u> to designate <u>cut</u>aneous-tact<u>ile</u> exteroception as a parallel phrase for auditory exteroception. He asserted that terms like invalid, pseudoauditory or vibrotactile hearing are negative terms which imply that the elicited thresholds should not be present. Nober (1968, 1969) contended that these "pseudoauditory" or "vibrotactile" thresholds should be present as they are the sensations mediated by another modality. Furthermore, Bocca and Perani (1960) asserted that the presence or absence of these thresholds was of pertinent diagnostic significance.

There is impressive evidence that the low frequency air and bone thresholds elicited at high intensity levels from deaf children are cutile and do not reflect auditory sensitivity. Some of these studies dealt directly with auditory sensitivity (Nober, 1963, 1964, 1967a, b; Langenbeck, 1965; Bocca and Perani, 1960; Smith, et. al., 1967; Harbert and Young, 1969) and other studies focused on vibrotactile sensitivity per se (Sherrick, 1953; Verrillo, 1962, 1963). Part of the difficulty is a fallacious assumption that the validity of the pure tone air and bone thresholds for normal hearing subjects (Whitting and Highson, 1940; Corso and Cohen, 1958; Albrite, et. al., 1960; Dadson and King, 1962; Harris, 1954) also applies to deaf subjects who receive the tones at high intensity output levels. The normative data were based on low intensity thresholds and not high intensity thresholds where other modalities can intervene. Deaf children give thresholds at levels marginal to normal discomfort where cutaneous-tactile perceptions are likely. Nevertheless, a tacit compliance prevails that the original validation on normal hearing subjects also applies to the deaf.

The maximum output levels on the modern audiometer are governed by discomfort thresholds established from normal hearing subjects. For example, at 125 Hz the maximum sound pressure level output is 135.5 dB; at 250 Hz, it is 114.5 dB; at 500 Hz, 121 dB; at 1000 Hz, 116 dB; at 2000 Hz, 118 dB; at 4000 Hz, 119 dB and finally, at 6000 Hz, 118 dB (Nober, 1966c). Energy at these extreme output levels must certainly activate cutaneous and tactile receptors. Some low frequency sounds approach and even surpass the discomfort where pain receptors become involved (Verrillo, 1962, 1963;

Sherrick, 1953). With recruitment present, the discomfort levels are even lower than for non-recruiting ears. Many deaf children assert that they feel "pressure" and do not actually hear the tone, particularly in the lower frequencies. The studies of Verrillo (1962), Bekesy (1960), and Sherrick (1953) showed that the skin sensitivity function relative to vibrotactile stimulation has a U-shaped configuration with maximum sensitivity near 250 Hz. The characteristic auditory configuration also is a U-shaped pattern.

Nober (1963) investigated air conduction thresholds of 42 deaf children relative to audiogram configuration, test-retest reliability, percentage of no response, standard deviation and standard error of measurement. The results, relevant to this proposal, depicted a median audiogram configuration of 75 dB at 125 Hz, 80 dB at 250 Hz, 100 dB at 500 Hz, 110 dB at 1000 Hz and no response at 2000, 4000, and 6000 Hz. These thresholds represent statistical values. Actually, 60% responded at 125 Hz, 95% at 500 Hz, 81% at 1000 Hz, 62% at 2000 Hz, 40% at 4000 Hz, 37% at 6000 Hz, and 8% at 8000 Hz. It is pertinent and suspicious that 90% or more responded at 250 and 500 Hz where the characteristic U-shaped configuration for skin sensitivity reaches its maximum (Verrillo, 1962; Bekesy, 1960; Sherrick, 1953). Furthermore, Arnold, et. al., (1963) showed "feeling curves" that were similar to the Nober (1963) air conduction values; Schlosser, et. al., (1964) discussed similar air values for deaf children. Finally, Langenbeck (1965) reported "feeling" thresholds that were nearly identical to the Nober (1962) and Arnold (1963) data.

In another study, Nober (1967) placed the air conduction receiver in the palms of the hands of 94 deaf subjects to obtain "palmar" thresholds for different age children. These results showed little or no variation relative to age with a relatively narrow range of values. All 94 subjects yielded palmar thresholds at 125, 250, and 500 Hz, while only one-third to one-half responded at 1000 Hz, depending on the age group. The palmar threshold values (age pooled) were: 70 dB at 125 Hz; 80 dB at 250 Hz and 100 dB at 500 Hz. There were no palmar thresholds at 1000, 2000, 4000 and 6000 Hz, respectively. When these values were compared to those elicited at the ear level in the conventional manner, the palmar thresholds were 5 dB more sensitive at 125 and 250 Hz, equal at 500 Hz, and poorer beyond this frequency. The similarity of the palmar and ear level thresholds suggested that the ear level values were cutile. The superior palmar low frequency cutile threshold was expected as palmar integrement is inherently more sensitive to vibrotactile stimulation.

Bone conduction studies also demonstrated cutile thresholds. Nober (1964) originally depicted low frequency bone thresholds of some deaf children as "pseudoauditory" and later reported further evidence of "vibrotactile" exteroception for bone conduction thresholds. He demonstrated bone conduction thresholds at 125, 250, 500 Hz, and occasionally 1000 Hz from children with profound sensorineural deafness. These bone thresholds created a fallacious and suspicious air-bone gap that cannot be corrected surgically and should be interpred with caution (Schucknecht, 1967). Furthermore, the bone thresholds occasionally were elicited from subjects who even failed to yield air thresholds at maximum output;

total lack of response relatively uncommon as most deaf subjects showed some cutile sensitivity in the low frequency tones. Swisher and Gannon (1968) reported that 21% of their subjects failed to yield bone responses. On some occasions total lack of response was limited to one ear as the other yielded cutile thresholds. Cutile bone thresholds are conspicuously homogeneous, considering the disparate etiologies and pathologies associated with sensorineural deafness.

Barr (1955) noted these low frequency bone thresholds with his deaf subjects and designated them "artifacts". Bocca and Perani (1960) described them as an "audiologic absurdity" and explained the dynamics in terms of a primitive vestibular hearing mechanism that was mediated through the vestibular endings in the saccula and cochlea; they cited anatomic, physiologic, and clinical evidence to support their theory of "vestibular hearing". Langenbeck (1965), and, Harbert and Young (1969) are nearly identical, i.e., 40 dB at 250 Hz and 64 dB at 500 Hz (corrected to ISO). In isolated instances, Nober (1964) found some bone responses at 1000 Hz but these occurred without regularity. Harbert and Young (1969) reported they were unable to elicit bone responses at 1000 Hz or above. Martin and Wittich (1966) and Smith, et. al. (1967) reported bone thresholds at 100 Hz in several of their patients.

Nober (1964) demonstrated that cutile bone thresholds could be audiologically differentiated from auditory bone thresholds with an intense masking sound. He hypothesized that an auditory masking stimulus should not shift non-auditory thresholds but should increase auditory thresholds by a relatively linear amount. Subsequently, he gave "partially deaf" sensorineural subjects and mixed loss subjects white noise that exceeded their respective air conduction thresholds by approximately 15 dB at 250 Hz and 20 dB at 500 Hz. The results confirmed his hypothesis as the sensorineural group with the cutile thresholds did not reveal statistically significant masked bone conduction shifts; the mixed loss group with valid bone thresholds manifested a 15 dB shift at 250 Hz and a 22 dB shift at 500 Hz, both significant at the 1% level of confidence. Smith, et. al. (1967) concurred with this procedure and noted that a comparison of the thresholds obtained for mastoid and forehead placement of the bone oscillator was also relevant.

C. Purpose and Scope

The above review revealed supportive evidence that air and bone audiograms of many deaf children are cutile rather than auditory thresholds. Anesthetizing ears is an impractical procedure to identify totally deaf children. It is essential to develop some audiologic criteria or trends from currently available auditory tests to serve this purpose. Although this may be difficult, there is prevailing evidence that some procedures are discerning. This study purports to gather, evaluate, and analyze the psychophysical data of totally and partially deaf children. There is a dearth of information on the hearing function of deaf children, particularly on a differentiation between auditory and cutile thresholds.

The ramifications are certainly extensive to both therapy and education. Some of the difficulty many deaf children exhibit in using hearing aids may reflect cutile audiograms which are devoid of any auditory reserve. Do these children manifest any difference in other performance areas such as achievement level, speech and language ability, etc.? How effective is a small residual amount of hearing? Currently no evidence is available with the dichotomy of cutile and partially deaf. Perhaps the current classroom emphasis on auditory stimulation for the deaf may be inadvisable for some students. Pupil expectation level of the classroom teacher could be modified if more information and knowledge were available regarding the general integrity of a student's auditory mechanism.

D. Audiologic Battery

The extensive degree of hearing loss limited the nature and techniques of the hearing tests that could be given, particularly the supraliminal tests. As a result, some modifications were necessary and innovations were implemented. All the tests described below were used. Discussion will review the rationale, validity, reliability, and psychophysical technique of each test. In Chapter II, the exact procedures and modifications for this project are fully described:

1. pure tone air conduction thresholds. The conventional pure tone air conduction audiogram was the basis of all audiologic tests. Sound traveling and auditory route, e.g. the external auditory meatus to the middle ear and the inner ear and then the retrocochlear pathways to the brain reflects the integrity

of the auditory mechanism as a functional unit, assuming the subject is conditioned and cooperative. Pure tone thresholds do not provide the same integrative data as speech tests, but considerable inference is possible from the former. The pure tone audiogram gives some information of the hearing level in relation to the norm, the types of loss, and the locus of pathology; in some instances, the etiology can be speculated from the audiogram pattern. Validity and reliability have been substantiated on normal and also hearing impaired subjects. However, the validity of some profoundly deaf audiograms is in serious question and the topic of this report. The reliability of profoundly deaf audiograms is quite good (Nober, 1963; Elliot, 1967). Rapin and Costa (1969) found on occasions 20 dB retest differences, but these deaf children had mental retardation, brain damage, auditory imperception, emotional disturbance, etc., all of which was ostensibly excluded from the Nober (1963) study.

2. <u>pure tone bone conduction thresholds</u>. Sound is generated with a bone oscillator so the tone bypasses the external and middle ear conductive mechanisms as it ascends the auditory pathways to the brain. The difference in thresholds sensitivity between the air and bone thresholds, i.e., the air-bone gap, is an index of the conductive impedence. Collectively, valid air and bone thresholds at each frequency depict the degree of loss attributed to the conductive and sensorineural mechanisms. The bone audiogram represents the sensorineural component of the hearing assessment while the air audiogram designates the conductive and sensorineural components.

3. frontal vs mastoid placement. The site of the bone oscillator placement is pertinent. As early as 1938 Barany advised that the mastoid was a poor placement location because of inertial and compressional osseous movements; he suggested the forehead which has been reported as more reliable (Kirikae, 1959; Hart and Naunton, 1961; Studebaker, 1962) in spite of the impending threshold elevation of 10-20 dB. Smith, et. al. (1967) concurred and used the comparison of the thresholds obtained for mastoid and forehead placements of the bone oscillator to differentiate between the cutile and partially deaf subjects. They found auditory mastoid thresholds were 10 dB better than auditory forehead thresholds but the cutile mastoid and forehead thresholds remained essentially the same. Martin and Wittich (1966) also reported that the threshold difference between mastoid and forehead placement gave supportive evidence to differentiate between auditory and cutile bone conduction thresholds.

4. occlusion-absolute bone conduction. Bone conduction thresholds and transmission can vary under a number of internal and external conditions, e.g. frequency, intensity, noise interference, occlusion, etc. For example, high intensity bone transmission differs from low intensity bone transmission but both involve "bone-tissue" conduction, a term preferred by a number of research clinicians. Bone-tissue conduction even occurs in an air conduction sound field (Bekesy 1949; Zwislocki, 1957) although these thresholds are clearly 50-70 dB weaker than the air conduction curves below 1000 Hz and 40-55 dB poorer above 1000 Hz.

Conventional bone conduction thresholds normally represent "relative" values since the external auditory meatus is unoccluded to the external environment. After the introduction of the Rainville procedure (1959) which employed "absolute" bone values, a number of absolute procedures evolved. All have one imposing detrimental foil to universal validity, the "occlusion effect", which varies, depending on the pathogenic etiology.

The occlusion effect precipitates a demonstrable increase in threshold sensitivity (a lowered threshold) or a subjective increase in loudness perception. It is more pronounced in the lower range, i.e., 15 dB at 250 and 500 Hz, 5 dB at 1000 Hz, negligible beyond 1000 Hz and occurs mostly with normal and sensorineural ears. Intersubject variability is comparable to unoccluded bone thresholds (Sullivan, et. al., 1947; Siegenthaler, et. al., 1957; Dirks and Swindeman, 1967). The dynamics of the occlusion effect are conjectured as due to meatel resonance, environmental masking, compression of the meatus by the head of the mandible (Huizing, 1960; Hallpike, 1930; Bekesy, 1960) but the issue is still controversial.

5. Bekesy audiometry. Bekesy first described his audiometer in 1947 which was the forerunner of all automatic units. Reger (1952) modified it and subsequent to that time Bekesy audiometry has become the most valuable single audiologic instrument for auditory assessment and evaluation. The Bekesy audiometer uses a method of adjustment procedure where the subject controls the intensity dial, not the examiner. Frequency is automatically programmed as a continuous, ongoing stimulus systematically rising from a low to a high frequency.

This ongoing sound can be generated as an interrupted (pulsed) or a steady (continuous) tone. The threshold levels and audiogram configurations that emerge from the continuous and interrupted presentations have pertinent otologic and audiologic significance.

Continuous and interrupted tracings have received incessant scrutiny since they were classified into four types by Jerger (1960) and a year later, a fifth type (Jerger and Herer, 1961). Types I-IV, inclusive, ostensibly connote some type of organic pathology while Type V indicates psychogenic involvement. Normal and conductive ears generally manifest the Type I Bekesy where the continuous and interrupted tracings intertwine. Occasionally, a cochlear involvement simulates Type I. Cochlear impairments are most often Type II pattern where the continuous tracing decreases 10-15 dB below the interrupted and runs parallel throughout the range. Cochlear impairment also produces a Type III tracing but Type III is more often associated with eighth nerve damage. In this pattern, continuous and interrupted separation starts immediately, continuous sensitivity tracings remain lower than interrupted throughout the frequency range and may even extinguish around 1000 Hz. Eighth nerve cerebello-pontine angle tumors frequently yield the Type IV configuration where the continuous tracing is markedly poorer than the interrupted. Type V is exclusively symptomatic of functional involvement or poor conditioning; here, the tracings are reversed as the continuous is better than the interrupted.

Bekesy tracings per se have a high correlation with conventional thresholds for both children and adults (Stark, 1968 a, b).

The thresholds are determined, in most instances, as the midpoint value of the upper and lower peaks for a given frequency although Harbert and Young (1966) found the bottom spike was better. The bottom spike is where the tone becomes audible and the upper spike where the trace effect dissipates and the tone becomes inaudible.

Bekesy audiograms can provide considerable information when specific variables are examined. For example, the tracing range can be construed as a tone decay pattern and also as an index of differential sensitivity; hence, there is pertinent site of lesion information in the range data. Masking also affects the continuous and interrupted tracings (Simon and Northern, 1966; Blegvad, 1967, 1968). Even the audiogram classification relative to type (Blegvad, 1968) is affected by masking as thresholds become more acute with contralateral masking (Simon and Northern, 1966). Attenuation rate (Harbert and Young, 1966), off-time periods (Jerger and Jerger, 1966, 1967) emotional change, and personality (Shepherd and Goldstein, 1966, 1968) are reported to affect the Bekesy results.

Without question, the greatest amount of investigation relates to the classification of Types I-IV. Hopkinson (1966) suggested reclassifying the tracings in terms of the configuration descriptions. Menzel (1966) cautioned against erroneous site of lesion inferences from the tracing classification types. For example, Hughes, Winegar and Crabtree (1967) reported cochlear lesions can yield Types II and IV. Type V occurred with normal ears (Locke and Richards, 1966), probably due to loudness memory relative to the sustained and interrupted tones (Hattler, 1968)

Frisina and Johnson (1967) used the Bekesy procedure on deaf subjects who ranged in age from 2 1/2 years to 12 years. As subject comprehension of the procedure is critical for valid results, they introduced a bone oscillator as a vibrotactile, nonverbal conditioning instruction reinforcement. Results showed good cross-modality and stimulus generalization for most age groups, with older subjects generally performing better. Bekesy audiometry was successful with deaf subjects and Frisina and Johnson (1967) recommended vibrotactile reinforcement as part of the conditioning instructions. So far, there has been no report in the literature of attempts to classify the audiograms of deaf children into the Bekesy types.

6. intensitive-difference-limen. Another type of threshold which has pertinent diagnostic value is the differential threshold, i.e. the smallest perceptible incremental change in any given stimulus parameter. Diagnostically, the intensive parameter has been most fruitful although a number of studies have concentrated on the frequency parameter (Hudgins, 1955; and Harris, 1952). In audiometrics, the emphasis was to develop an intensive difference-limen (DL) test as a standardized assessment procedure.

The difference-limen represents the just-noticeable-change (Stevens and Davis, 1938). In normal ears, DL size relates functionally to variables such as tone duration, intensity, fluctuation rate, frequency, monaural vs binaural presentation, sensation level, transition between tones and the magnitude of the stimulus increment (Knudsen, 1923; Riesz, 1933; Churcher, et. al., 1934; Upton and Holway, 1937; Montgomery, 1935; Rawdon, Smith and Grindley, 1936; and Stevens and Davis, 1938). Several

DL techniques were developed in an attempt to standardize a DL test (Bekesy, 1947; Luscher and Zwislocki, 1950; Hood, 1950; Denes and Naunton, 1950; Jerger, 1953; Dix and Hood, 1953). As most of these tests had some limitation (Harris, 1954; Hirsh, et. al., 1954), Jerger, Shedd and Harford (1959) developed the short increment sensitivity index test, commonly abbreviated, the SISI test. This last modification has prevailed for the past decade as the most universally used DL test for locating the site of auditory pathology. It is an easy test to both implement and quantify.

Specifically, the SISI test measures differential sensitivity to 1 dB increments periodically superimposed on a sustained 20 dB sensation level pure tone. A total of 20 presentations are given at 5 second interstimulus intervals. Each intensity increment reaches maximum amplitude rise and amplitude decay in 50 milliseconds periods each with a 200 milliseconds maximum duration. As 20 superimposed 1 dB increments are given, each increment presentation contributes 5% toward the maximum 100% score.

Generally, a SISI score of 0% to 25% is considered normal or mild; 26% to 50% is mild to moderate; 51% to 75% is marked and 76% to 100% is severe. Normal, conductive retrocochlear ears fall in the first group while cochlear losses score in the higher ranges, particularly at the higher frequencies, i.e., 4000 Hz. One exception is presbycusis which will vary markedly from 0% to 100%. Higher frequencies have better test-retest reliability and interval consistency, possibly because losses are greater in the upper range; the poorest reliability is at 250 Hz. Approximately a third of the subjects with cochlear pathology fail to yield positive SISI scores at 500 Hz (Harford, 1967). It was at 250 and 500 Hz where most of the deaf subjects in this study responded and were tested in this investigation.

7. localization in a minimum audible field. Two techniques for measuring the absolute threshold of the ear have predominated in audiometric assessment, i.e., the minimum audible pressure (MAP) and the minumum audible field (MAF). Since absolute minimal sound pressure at the eardrum cannot be measured directly, it is determined by generating a known suprathreshold pressure and then interpolating the absolute minimum value. Numerous investigators have determined threshold values for these conditions throughout the audible frequency range, i.e., 50 Hz to 12,000 Hz (Sivian and White, 1933; Bekesy, 1960; Wegel, Riesz, and Blackman, 1932).

The MAP can be determined in two ways, i.e., through earphones or with a probe tube. In the latter, a small search tube is coupled to a microphone and calibrated on an assumption that the pressures at the drum and at the end of the tube are identical; this technique is more commonly used with animals. Earphone measurements assume a tight coupling to the ear with a closed chamber volume in the auditory meatus of known dimensions; from this known value the eardrum pressures are computed. With adults, the encapsulated air volume is considered equivalent to a cylindrical volume of 6cc.

MAF is determined by generating a given intensity for the sound in the field without the observer present and then have him enter the sound field to listen. As the presence of the subject will alter conditions due to body and head absorption, azimuth diffraction, etc., the process of establishing the actual measure without the subject standardizes the procedure and reduces the intervening variable effects.

MAP and MAF values are not identical; the latter can reach 20 dB more sensitivity than MAP, depending on the frequency (Sivian and White, 1933). Also, there is an approximate 3 dB to 6 dB improvement in threshold with binaural listening versus monaural listening. While the greater sensitivity for binaural listening is contended to be a neural phenomenon, the superiority of MAF over MAP is less clear. In the mid-range of hearing, the open chamber resonance dimensions of the external auditory meatus favor a spectrum around 3000 Hz. At the high range, head diffraction and the external pinna can account for some differences. But, at the low frequencies where the wave length is large and where structure, resonance and diffraction are inconsequential, the explanation is still, in part, unresolved. Sivian and White, (1933) have suggested that static pressure, temperature, acoustic impedance, fatigue, etc., could interact and serve as a partial explanation.

Localization of a tone in a sound field requires binaural interaction. High frequency tones are localized in space primarily from the intensity differences between the two ears and the low frequency tones primarily by the intraural phase differences. It is doubtful that non-auditory sensations can be localized in space, assuming that the speakers are sufficiently distant from the ears to avoid vibrotactile interference. Standing waves can be an artifactual variable for the higher frequencies but they are negligible at 250 and 500 Hz where the localization tests in this study were conducted. Intensity differences and phase differences between the two ears are also negligible at 250 and 500 Hz.

8. monofrequency and bifrequency identification in a minimum audible field. It is also unlikely that monofrequency-bifrequency identification in space is possible through vibrotactile sensation. In this instance, a 250 Hz and a 500 Hz tone were presented separately and then simultaneously; the subject had to indicate whether one or two tones were presented. This is not a conventional or standard procedure but rather an innovation for the purpose of this investigation.

9. tone decay. Tone decay provides information about the integrity of the retrocochlear mechanism by measuring the presence or absence of abnormal threshold sensitivity adaptation or "relapse" to a continuous tone (Hallpike and Hood, 1951). Generally, a 0-15 dB shift is considered within normal range, a 20-25 dB shift occurs with organ of Corti pathology and a shift of 30 dB or more is a positive indication of retrocochlear pathology. Absence of abnormal tone decay does not preclude retrocochlear eighth nerve cerebello-positive angle tumors or acoustic neuromas but the presence of this adaptation is a positive indication (Brand and Rosenberg, 1963). While the test has been used to ascertain other hearing anomalies, it is most efficient as an index of retrocochlear pathology (Hopkinson and Thomas, 1967; Rosenberg, 1969) and is used exclusively for this purpose.

The tone decay test was developed at Northwestern University in 1954 and later described by Carhart and Jerger (1959). A tone is presented at threshold and must remain audible for one minute. If the tone becomes inaudible before 60 seconds, the intensity is increased 5 dB or more if necessary until the tone remains audible for 60 seconds. The final hearing level that is needed for 60 seconds of audibility minus the original threshold is an index of the amount of tone decay or auditory adaptation. Rosenberg (1958) modified this procedure by presenting the tone for a grand total 60 seconds, but increased the intensity in 5 dB increments as needed for the patient to hear the tone without interruption for this one minute period. More recently, Owens (1964) modified the test further by starting 5 dB above threshold and, if the tone faded, he allowed a 20 second rest interval before the next increment was presented. He described three classifications: Type I or no adaptation; Type II, progressively slower decay with each 5 dB increment; and Type III, little or no change in adaptation rapidity with the 5 dB intensity increments. Owen's (1964) Type III related to the Bekesy Type III pattern that was associated with eighth nerve lesions. Bekesy Type III tracings depict the process of auditory adaptation; here the continuous tracing quickly falls below the interrupted tracing.

10. <u>speech reception threshold</u>. Functionally, it is important to know how well a subject can hear and recognize speech. The speech reception threshold connotes the hearing level where the subject can recognize 50% of the words, i.e., spondee words.

These words are bisyllabic and quite homogeneous so they are particularly well suited for threshold measurements. This value generally correlates to the pure tone average (PTA) at 500, 1000, and 2000 Hz for normal and conductive ears but is less likely to correspond as well with sensorineural and retrocochlear pathology. As the degree of hearing loss increases, the relationship between the SRT and PTA wanes. There is pertinent diagnostic as well as functional information in speech tests. The validity, reliability and use of this measure is well documented as the test is an integral part of any basic audiometric battery.

Severely deaf, as a group, are almost untestable with conventional speech audiometry. While an isolated individual occasionally gives measurable responses, these are relatively fragmentary and when averaged as a collective value they fade into obscurity. Possibly, group differences may emerge depending on the type and emphasis of language training at an educational institution. Nober (1963) reported the speech reception thresholds of 46 students as median values for a group of deaf children at an oral school for the deaf. When his pure tone average (PTA) exceeded 91 dB, the median SRT was 99 dB. This value was only based on part of the 46 students as many subjects were unable to yield speech thresholds.

11. intelligibility. Another speech hearing test that is basic to any audiometric evaluation is the discrimination or articulation score. This indexes the ability to discern or recognize the finer differences in phonetic units when the material is presented at a comfortable listening level. Under normal

conditions, the words are given 40 dB above the SRT but with extreme sensorineural impairment this is not feasible and a lesser level is chosen. Discrimination scores represent the ability to understand speech under ideal listening conditions. Monosyllabic words that are "phonetically - balanced" are typically used and a score is a percentage fraction relative to a 100% maximum rather than a decibel unit. Pertinent diagnostic information and functional data for the use of amplification are gleaned from the PB scores.

Again, with markedly deaf children, it is doubtful that any reasonable scores can be elicited. When the thresholds approach the extreme output of the audiometer (marginal to discomfort) it is not possible to give these words at a "suprathreshold" level that is comfortable. Most often, the deaf subject has a perceptual range from inaudible to discomfort which is limited to 5-10 dB and this is associated with marked auditory distortion. Nevertheless, discrimination scores will be obtained for comparative differences, if possible.

12. sensorineural acuity level (SAL). Rainville (1959) pioneered the first major change in conventional bone conduction audiometry by obtaining absolute bone conduction thresholds. The test was designed to circumvent the intricacies of masking. As the Rainville test was complex to administer, it was quickly simplified by Lightfoot (1960) who introduced the use of normal hearing subjects as a predetermined reference. Subsequently, Jerger and Tillman (1960) modified the Lightfoot procedure and called it the sensorineural acuity level (SAL) test.

The major innovation the use of occluded absolute bone thresholds rather than the relative bone values of conventional bone audiometry where the test ear is left unoccluded. A masking noise is generated through the bone oscillator located on the forehead and the pure tone is presented through conventional earphones. Problems are minimized relative to which ear to mask, the amount of masking, calibration and even environmental noise. The cardinal deterrent is the occlusion effect which causes spurious results relative to frequency, subject variability, degree of loss, acoustic reflex, and site of pathology.

The SAL test cannot be used with subjects whose sensorineural impairments exceed 50-60 dB. This limitation is mechanical due to the bone oscillator's 4 volt rms maximum beyond which there is marked nonlinearity. Jerger and Tillman (1960) used a 2 volt rms output (i.e., 120 dB) to obtain their normative shift values of 20 dB at 250 Hz, 45 dB at 500 Hz and 50 dB shifts at 1000, 2000 and 4000 Hz. Even with a 4 volt rms output and the improvement provided by narrow band masking (Keys and Milburn, 1961; Simon, 1964; Menzel, 1965), severely deaf subjects are precluded from using the SAL procedure. As it turned out in this study, it was not possible to include this procedure because of the extensive hearing losses of the subjects.

CHAPTER III

METHODS

A. General Plan

The general plan was to investigate the psychoacoustic function of severely deaf students with conventional hearing tests and some innovative procedures. Results were also analyzed to determine whether the audiometric data differentiated between cutile and auditory audiograms.

B. Subjects

All subjects were deaf students in residence at the New York State School for the Deaf, Rome, New York. Initially, 45 students were included but due to illness, dropout, transfer, etc. only 32 subjects completed the tests. The criteria for selecting subjects were: congenital deafness with an otologically confirmed bilateral, profound sensorineural loss; normal intelligence; good emotional stability; no history of brain damage and an age between 11 to 18 years, inclusive. None of these subjects had participated in any previous research with this author.

Thirteen girls and nineteen boys participated in the total study. Table I shows the detailed age statistics as calculated at the outset of the study. The total mean was 15 years, 1 month and the total range 10 years, 1 month to 18 years, 7 months. The IQ scores are shown in Table 2 relative to sex and group distribution. The range for boys was 94 to 123, for girls 85 to 132, and 85 to 132 for the total. The mean IQ was 103.3 for boys, 101.1 for girls, and 102.3 total. IQ data for groups showed means of 101.8, 113.8, 101.7 and ranges 85-123, 101-132,

Table 1

Age distribution for the 32 experimental subjects.

	Males	Females	Total
Mean	14 yrs., 9 mos.	15 yrs., 2 mos.	15 yrs., 1 mo.
Median	14 yrs., 1 mo.	15 yrs., 6 mos.	15 yrs., 6 mos.
Mode	12 yrs., 2 mos.	15 yrs., 6 mos.	12 yrs., 2 mos.; 15 yrs., 6 mos.
Range	11 yrs., 7 mos.; 18 yrs., 7 mos.	10 yrs., 1 mo.; 18 yrs., 1 mo.	10 yrs., 1 mo. to 18 yrs., 7 mos.

Table 2

Intelligence Quotient scores for the experimental subjects.

A. Sex

	Males	Females	Total
Mean	103.3	101.1	102.3
Median	103.5	98.5	103.0
Mode	103.4	92.0	103.0
Range	94-123	85-132	85-132

B. Groups

	A	B	C
Mean	101.8	113.8	101.7
Median	100.5	111.0	101.0
Mode	--	107.0	103
Range	85-123	101-132	90-108

90-108 for groups A, B, C, respectively.

C. Classification of Data into Groups

There were two ways of determining how the data would be classified into three groups, i.e., A, B and C, both based on the conventional air conduction thresholds. One designation classified each subject per se into one of the three groups based on his air conduction audiogram of the better ear; the second designation classified each ear independently into one of the three categories. The classification depended on the nature of the test.

1. Classification based on better ear. The rationale for employing the better ear criterion was based on the assumption that the integrity of the better ear generally governs the behavioral performance to auditorilly mediated stimuli. Indeed, an extreme instance of one normal and one totally deaf ear is rarely noticed in the general performance of the individual. Table 3 lists the 32 subjects as classified into groups A, B or C relative to the better ear.

2. Classification of each ear independently. In this instance, each ear is assumed independent in regard to psychoacoustic performance and subsequently was separately categorized into Groups A, B or C based on the conventional air conduction audiogram. Table 4 depicts this arrangement and shows that twenty of the thirty two subjects d bilateral audiograms that were homogenous enough for both ears to be included in either of the three groups, e.g. there were 12 bilateral ears in Group A, three in Group B and five in Group C. In most phases of audiometrics, it is precendented to assume psychoacoustic

independence of the left and right ears. Thus, a conductive left ear and a sensorineural right ear yield markedly different data in a variety of audiometric tests.

D. Criteria for Determining Group A, B and C

Groups A, B and C were determined on the basis of the conventional air conduction thresholds. Group A designated threshold responses up to 750 Hz, inclusive. Group B was comprised of air conduction responses that included 1000 Hz. This group was formed separately to test controversial contention of some audiologists that these audiograms represent auditory thresholds; this author personally believes this group constitutes a partially deaf contingent. Group C threshold responses extend to 2000 Hz and above; these thresholds represent valid hearing responses.

When the better ear classification was employed (Table 3), there were twelve subjects in Group A, 6 subjects in Group B and 14 in Group C totaling 32 subjects. When the independent ear classification was used (Table 4), there were 32 ears represented in Group A, 13 ears in Group B and 19 in Group C, totaling 64 ears.

E. Environment

Initial screening tests to select subjects were conducted over a period of time at the Rome school in a quiet location remote from noise, traffic, etc. The specific tests described throughout were conducted in the soundproof suites at Syracuse University as subjects were bussed to the University for testing in an IAC 16041 audiometric suite.

F. Instrumentation

The audiometer originally ordered for this project was the

Table 3

Classification of experimental subjects into Groups A, B and C on the basis of the better ear.

Group A	Group B	Group C
3	1	2
4	14	7
5	23	9
6	24	11
8	27	15
10	30	16
12		17
13		18
22		19
26		20
28		21
29		25
		31
		32

Table 4

Classification of experimental subjects' ears into groups A, B and C.

Group A		Group B		Group C	
		1L*,	1R**		
		2L			2R
3L,	3R				
4L,	4R				
5L,	5R				
6L,	6R				
				7L,	7R
8L,	8R				
		9L			9R
10L,	10R				
			11R	11L	
12L,	12R				
13L,	13R				
14L,			14R		
	15R			15L	
				16L,	16R
		17L			17R
18L					18R
19L					19R
				20L,	20R
				21L,	21R
22L,	22R				
		23L,	23R		
24L			24R		
25L					25R
26L,	26R				
		27L,	27R		
28L,	28R				
29L,	29R				
30L			30R		
	31R			31L	
				32L,	32R

*L = right ear

**R = left ear

Beltone CR-5000. Because of assembly delay, the instrument never became available during the study. In substitute, a new Beltone 15C was provided by Beltone. A Grason-Stadler Speech Audiometer (E640) was used for the speech tests; a Maico M24 was set up for the sound field tests. All sound field values were measured with a Bruel and Kjar sound level meter with the subject not present. A Grason-Stadler Bekesy Audiometer was employed for the Bekesy tracings. All instruments were calibrated at the outset and checked periodically. A high quality tape recorder recorded the speech articulation data for future analysis. For the occlusion tests, rubber earplugs were inserted into the external auditory meatus for a tight seal and maximum occlusion.

G. Audiologic Procedures

1. pure tone air conduction thresholds. The conventional air conduction audiogram formed the basis of audiologic evaluation. Subjects were classified solely on the conventional air conduction thresholds. An ascending-descending technique as described by Carhart and Jerger (1959) was used when appropriate; for those subjects who responded at the audiometric limit, only the ascending technique was possible. Thresholds were replicated several times to obtain the lowest or best threshold values. Each ear was tested separately through earphones. In instances when the subject failed to report at maximum output, a "no response" (NR) designation was recorded. When the means were later computed, the NR was coded by adding 5 dB to the maximum output at that frequency. This technique has precedence (Nober, 1963). Table 5 depicts the

proportions of responses and NR's relative to groups, frequency, ear and mode of presentation.

2. pure tone bone conduction thresholds. The bone conduction thresholds that were part of the basic sensitivity measures were taken from the mastoid bone in the conventional psychophysical manner. Caution was exercised to ensure the tone was only heard in the test ear. As both ears had extreme hearing loss, most responses to bone conduction were at maximum output. Table 5 shows the proportions of responses and NR's. Masking was not used for these conventional thresholds in order to minimize confounding variables at this level.

3. mastoid vs frontal placement bone conduction thresholds. In this instance, the bone oscillator of the Beltone 15C was placed alternately on the mastoid process and the forehead for relative bone conduction thresholds. Placement order was randomized to deter sequential artifacts. Conditioning followed the patterns described earlier. The bone oscillator was held tightly against the mastoid and forehead areas with a strong flexible headband. A slide adjustment made it adaptable to the different head sizes.

4. occlusion test. After the unoccluded (relative) mastoid and frontal bone thresholds were obtained in conventional manner, the absolute thresholds were obtained for 250, 500 and 750 Hz, with the ear canal occluded. These measures were also elicited from the mastoid and frontal areas with alternate ipsilateral and contralateral ear occlusion. Rubber earplugs sealed the external auditory meatus. They were repeatedly cleaned with alcohol

Table 5

Distribution of subjects who yielded and failed to yield threshold responses to tones at intensities within the audiometer limits.

		Air			
		Left		Right	
Group	Hz	NR*	R**	NR	R
	250	4	14	4	10
A	500	5	13	3	11
	750	4	14	12	2
	250	0	6	1	6
B	500	0	6	0	7
	750	0	6	0	7
	1000	0	6	0	7
	250	0	8	0	11
	500	0	8	0	11
	750	0	8	0	11
C	1000	0	8	0	11
	2000	0	8	0	11
	4000	2	6	4	7
	6000	3	5	5	6

*NR = no response
**R = response

to prevent contamination from subject to subject. During the early exploratory stages, students were instructed to raise the hand that corresponded to the ear where the tone was ostensibly present. This particular phase created such confusion that it was finally abandoned. Test-retest data demonstrated extremely poor reliability.

5. Bekesy audiograms. All students were carefully conditioned to take Bekesy tests. Directions were first given in written form and then reinforced with manual signs by a teacher of the deaf who also held ASHA certification in Audiology. Practice sessions were held until the examiner was convinced the student understood the procedure and responded well.

The tone stimulus was given at the faster speed which runs from 120 Hz to 10,000 Hz in 3 1/3 minutes. Tests were conducted with the examiner present to ensure the student was actively cooperative. Both the right and left ears were tested with continuous and interrupted tone presentations.

6. intensive difference-limen modified (SISI). It was hardly possible to give the conventional SISI which is standardized at 20 dB above the subject's sensation level threshold; indeed the hearing losses were all so profound so more thresholds were at the limit of the audiometer. It seemed expedient to present the steady tone at some predetermined constant sensation level value that would include the largest number of subjects. Thus, the absolute threshold was chosen as the constant level for the steady tone. Intensity increments were presented sequentially at 5, 3, 2, and 1 dB. Essentially, this is an innovated intensive difference-limen test that simulated the SISI protocol. Another

modification was that only ten pips of intensity was presented at each of the four incremental levels to reduce the length of the sessions.

The ten incremental intensity pips were given to each ear separately at 250, 500 and 750 Hz for both air and bone conduction. As this phase of the test was tiring, rest intervals were used between the air and bone presentations and alternating ears. The difference-limen was the percentage of correct incremental recognitions. Here, too, instruction was initially in written form and reinforced with manual signs.

7. localization in minimum audible field (MAF). A Maico MA8 audiometer with matched speakers was used in the IAC soundproof suite. Speaker output was measured with a Bruel and Kjar sound level meter at ear level positions with the subject not present in the sound field. Speaker placement was two feet from each ear position of the seated subject. Frequencies 250 Hz and 500 Hz were used as most subjects yielded responses at these frequencies. An SPL of 114.0 dB was reached at 250 Hz and 121.0 dB for the 500 Hz tone. Head baffle at these frequencies and intensities is negligible or less than 5 dB (Sivian and White, 1933). Each frequency was presented randomly with three replications through each speaker or a total of six. Collectively, each subject received twelve trials or six per frequency. Subject scores represented the percentage of correct right-left localizations at each frequency.

Subjects were instructed with written material which was reinforced with manual gestures. A trial session was implemented and when the student demonstrated adequate conditioning, the tests were performed.

8. monofrequency and bifrequency identification in a minimum audible field. For monofrequency-bifrequency identification of the 250 and 500 Hz tones, the identical physical setup described above was employed. Individual and combined tone presentations were given through both speakers simultaneously for six trials, in randomized fashion; three of the trials were the individual tones and three were combined tone presentations. The rationale for using simultaneous speaker presentations was to minimize localization as a source artifact. In this way, the response reflected the better ear if there was any difference between ears. Universally, the thresholds at 250 Hz and 500 Hz were so similar this was hardly an issue. A subject designated whether he heard one or two tones by raising one or two fingers. The score was the percentage of correct responses for the six trials. Both written and manual instructions were employed for the conditioning reinforcement.

9. tone decay. The sixty second Rosenberg (1958) modification of the original Carhart (1957) tone decay test was given with both air and bone conduction modes of transmission. Instructions were in written and manual forms. Frequencies 250 Hz and 500 Hz were used for this procedure. All air and bone thresholds were rechecked at the time of the tests. After the tones were audibly maintained at threshold for sixty seconds, the signal was cancelled. If the subject failed to respond immediately by lowering his hand to indicate the tone was no longer audible, conditioning was considered inadequate and additional reinforcement trials were presented. Lowering of the

hand at the end of sixty seconds served to check the cooperation of the subject.

10. <u>speech reception thresholds</u>. Spondee words were presented live voice via earphones to each ear separately through a Grason-Stadler E3664 speech reception audiometer. A trained male speaker with a clear resonant voice gave the words from the control suite. A 50% correct criterion was used to determine the thresholds. The subject seated in the test suite pointed to a picture of the word he heard through the earphones. Identifying a picture was essential as the speech of these subjects was often unintelligible as most deaf children rarely reach a three year minimum articulation score on the Templin Darley test (Nober, 1967; Carr, 1963; Houchins, 1954; Sykes, 1940).

11. <u>intelligibility scores</u>. Phonetically balanced words were given through the same speech unit described above at any intensity level that enhanced word recognition. Most of the deaf students required maximum or near maximum output. Only a few were unable to tolerate extreme output and requested reduced intensity. The responses of the student were written and later scored. Fifty words were given to each ear. All students received the same list of words in any of six randomized orders.

H. <u>Intelligence quotient</u>

The intelligence quotient scores of the deaf subjects were tested with the WAIS and the WISC depending on the age. All tests were given within six months of the experiment by a trained psychologist who was employed full time at the Rome School for the Deaf.

I. Data

The raw data were transferred from the original data sheets to fortran sheets by a professional employee of the Syracuse University Computing Center and subsequently punched on IBM cards. Each subject was identified by a coding system with all his data on three cards. Information from the cards was transferred to tape and all the analyses were conducted from the tape to print out sheets.

J. Statistical Analysis

1. pure tone air conduction thresholds. The air conduction thresholds and the NR coded values (Table 6) were averaged for group means and analyzed by analysis of variance for significant differences within the .05 and .01 confidence limits. Each ear was tested independently to determine group, frequency and mode of presentation effects as individual parameters and for interactions. Any parameter that was significant within the .05 and .01 limits was tested with a one-way analysis of variance relative to the ear, frequency and mode of psychophysical presentation. In many instances, a series of *t* tests determined whether the means for the three groups significantly differed from each other. Hence, the three groups were compared for statistical trends.

2. pure tone bone conduction thresholds. Bone conduction thresholds were limited to a relatively narrow decibel range with small population samplings so the data were not applicable to statistical analysis.

3. occlusion test. These results were not subjected to statistical analysis.

4. *Bekesy audiograms*. The Bekesy thresholds were determined by calculating the halfway distance between the upper and the lower peaks of the excursions and designating the closest 5 dB unit as the value. Bekesy data were computed for group means relative to a number of parameters: left and right ear; continuous and interrupted tone presentations (Table 7-10). A variety of analyses of variance tested parameter means for significant differences and interaction effects. When statistically significant differences were found, *t* tests were utilized for more discerning analyses of the data.

5. *intensitive difference-limen (DL)*. The intensitive difference-limen values were expressed as percentage of correct responses values at the four incremental levels. As the data were kewed, they were subjected to any arcsin transformation to normalize the percentage means. All DL values were presented throughout the arcsin form (Tables 11-20) for the statistical analyses. For example, in Table 13, the left ear values for the one-way analysis variance at the 5 dB increment are presented both as untransformed data (column XI 1/4) and as arcsin transfromed data (column S1). The *F* value of 14.2 for the untransformed data and 13.8 for the transformed data showed close agreement with both significant at the .01 level of confidence.

The air and bone DL values of the three groups and the population total were analyzed at each of four incremental decibel sensation levels above each subject's thresholds (i.e., 5,3,2,1 dB) for each ear separately at frequencies 250 Hz and 500 Hz. The parameters of groups, intensity increments and mode of presentation (air vs bone) were analyzed at 250 Hz and 500 Hz for the left and right ears. One-way analyses of variance were conducted separately for the left and right ears at 250 Hz and 500 Hz to determine whether the three groups means significantly differed from each other at each of the four DL intensity incremental levels.

6. localization in a minimum-audible-field (MAF). These data were presented as the percentage of correct identification in localizing the sound source to a speaker. As the distribution was skewed, the data were adjusted with the arcsin transformation for statistical analysis. A one-way analysis of variance was used to test for group differences at 250 Hz and 500 Hz (Table 21) and a matched $\underline{t}$ test (Table 22) between the 250 Hz and 500 Hz means for each of the three groups.

7. monofrequency-bifrequency identification in a minimum-audible-field. These values were similarly expressed as percentages of correct recognitions and converted to arcsin transformations for the one-way analysis of variance (Table 23).

8. tone decay. Contingency tables (Tables 25-27) were prepared for these data as the responses were restricted to an exceedingly narrow range.

CHAPTER IV

FINDINGS AND ANALYSIS

A. Audiologic Tests

a. pure tone air conduction thresholds. The air (and bone) conduction thresholds depicted in Table 6 are the group means for each ear at each frequency.

At 250 Hz (Table 6), the thresholds decreased progressively from the cutile group A to the partially deaf group C for both ears. Table 7, a summary of the one-way analysis of variance of the left and right ears (with the conventional presentation and the Bekesy continuous and interrupted presentations), shows that the conventional left ear group means differed significantly at the .01 level but just missed the .05 level in the right ear. This was not expected as the values for the right and left ears were within these decibles for the three groups.

At 500 Hz (Table 6) the mean air thresholds decreased progressively in the right ear from group A to B to C but the left ear group B was slightly larger than group C. The means were significantly different (.01 level) for both ears (Table 8). Left and right mean values were close for group A but farther apart for groups B and C.

At 750 Hz (Table 6), the group thresholds decreased progressively in both ears from the cutile to the partially deaf. The one-way analysis of variance showed significance at the .01 level (Table 9). Right and left ears were nearly identical.

At 1000 Hz, only groups B and C were included by definition. Again, both ears were nearly identical. However, the mean

Table 6

Conventional air and bone conduction thresholds expressed as mean decibel values for the three groups.

Air Conduction				Bone Conduction		
Group	Frequency	Left	Right	Left	Right	Frontal
A	250	88	88	35	35	42
	500	108	107	65	64	67
	750	NR*	NR	68	68	--
B	250	82	85	33	36	40
	500	88	98	63	64	64
	750	98	104	65	66	--
	1000	107	109			
C	250	79	81	36	36	40
	500	93	90	62	62	65
	750	93	93	66	65	--
	1000	96	96			
	2000	91	97			
	4000	96	103			
	6000	91	100			

*NR designates the mean exceeded the maximum limit on the audiometer.

For computation purposes, a coded value of 5 dB beyond the maximum output at any given frequency was employed.

Table 7

Summary of one-way analyses of variance at 250 Hz for the parameters of groups, conventional audiometry, Bekesy audiometry with continuous and interrupted presentations for the left and right ears.

Left

Group	Conventional Threshold	Bekesy	
		Continuous	Interrupted
A (18)	88.3	89.2	83.1
B (8)	81.7	86.7	86.7
C (6)	78.7	85.0	85.0
MSb	288.0	51.7	32.6
MSw	38.6	32.6	46.2
df	2,29	2,29	2,29
F	**7.4	1.6	0.7

Right

Group	Conventional Threshold	Bekesy Continuous	Bekesy Interrupted
A (14)	88.8	88.9	88.9
B (7)	85.0	86.4	86.4
C (11)	80.9	81.8	80.9
MSb	180.9	156.7	201.0
MSw	57.3	55.4	58.1
df	2,29	2,29	2,29
F	3.15	2.8	*3.5

* = .05 level of confidence
** - .01 level of confidence

Table 8

Summary of one-way analyses of variance at 250 Hz for the parameters of groups, conventional audiometry, Bekesy audiometry with continuous and interrupted presentations for the left and right ears.

Left

Group	Conventional Threshold	Bekesy Continuous	Bekesy Interrupted
A (18)	108.3	104.7	104.7
B (6)	88.3	96.7	92.5
C (8)	92.5	96.9	97.5
MSb	1252.1	248.1	388.2
MSw	66.7	88.1	78.0
df	2,29	2,29	2,29
F	**18.8	2.8	*5.0

Right

Group	Conventional Threshold	Bekesy Continuous	Bekesy Interrupted
A (14)	107.1	104.3	104.3
B (7)	97.9	100.7	99.3
C (11)	90.0	92.3	91.4
MSb	913.4	452.5	515.6
MSw	101.0	77.0	81.7
df	2,29	2,29	2,29
F	**9.1	**5.9	**6.3

* = .05 level of confidence
** = .01 level of confidence

Table 9

Summary of one-way analyses of variance at 750 Hz for the parameters of groups, conventional audiometry, Bekesy audiometry with continuous and interrupted presentations for the left and right ears.

Left

Group	Conventional Threshold	Bekesy Continuous	Bekesy Interrupted
A (18)	113.9	104.7	104.7
B (6)	98.3	100.8	100.8
C (8)	93.1	100.6	100.0
MSb	1398.7	63.3	87.8
MSw	53.7	33.3	47.4
df	2,29	2,29	2,29
F	**26.0	1.9	1.8

Right

A(14)	114.3	104.6	104.6
B (7)	103.6	102.9	102.9
C (11)	92.7	93.2	94.5
MSb	1435.6	433.6	333.3
MSw	74.0	71.7	58.2
df	2,29	2,29	2,29
F	**19.4	**6.0	**5.7

** = .01 level of confidence

differences of nearly 10 dB between group B and C reached significance at the .01 level in the left ear and the .05 level in the right.

The thresholds in the left ear at 2000, 4000 and 6000 Hz were somewhat better than those in the right ear (Table 6) but no further comparison was made as the values were based on so few responses (Table 5).

In general, the air thresholds revealed a progressive decrease in the threshold means from group A to group C. The significant differences appeared due to the cutile group A mean being significantly larger than the group B or group C means which were relatively close. The remarkedly similar thresholds of the left and right ears were striking. Thus, it appears that the thresholds of the cutile group in the lower frequencies are greater than the two other groups.

There is pertinent information in Table 5 about the distribution of subject responses that is not obvious from inspection of the means. Group A had a demonstrable number of "no response" designation at 250 Hz, 500 Hz and 750 Hz that almost was unique for this group. At all three frequencies, approximately 30-40% of the Group A subjects did not respond, while there were nearly always responses for Groups B and C at these three frequencies. This may indicate that most subjects in Group A are near or beyond the maximum output at these frequencies. As the maximum output precoded NR designations are only 5 dB apart, the means do not reflect this important information.

2. <u>pure tone bone conduction thresholds</u>. The bone conduction means for each ear are independently depicted in Table 6.

NR bone designations were coded with an additional 5 dB beyond the audiometer maximum of 40 dB at 250 Hz and 65 dB at 500 Hz and 750 Hz.

At 250 Hz, the mean right and left mastoid placement bone thresholds for groups A, B and C were quite homogeneous, i.e., 35-65 dB. Frontal placement values for both ears of the three groups were about 40 dB. Thus, these data were consistent with the studies that showed mastoid placement about 5 dB less than frontal placement. In this respect, the three groups were very similar. At 500 and 750 Hz, the mean thresholds were always about 64 dB for both ears with all three groups and mastoid placement revealed similar results. Thus, the bone conduction data were quite homogeneous and suggested that these were almost exclusively nonauditory responses.

The extremely narrow range of bone conduction responses and the limited number of responses precluded any conventional statistical analysis and interpretation. These data were quite inconclusive.

3. occlusion test. The technique of ipsilateral and contralateral bone conduction occlusion did not result in any demonstrable threshold shifts or lateralization. Indeed, these data, too, were inconclusive and not applicable to statistical analysis. If any conclusion can be gleaned, it is supportive to the conventional bone conduction results that suggested the responses were nonauditory thresholds. Thus, the occlusion test did not yield responses that were consistent with expected absolute and relative bone conduction thresholds or lateralization shifts. This procedure was not a fruitful technique to

differentiate among the cutile or partially deaf groups.

4. Bekesy audiograms. A summary of the mean air conduction Bekesy thresholds is depicted in Table 10. Both ears are listed separately at each frequency for the three experimental groups.

At 250 Hz (Table 10) the mean thresholds decreased progressively from group A to group C in both ears for the continuous presentation and in the right ear with the interrupted; the left ear interrupted threshold was less uniform. There was little or no difference between the ears for the continuous in either ear. Thus, the means at 250 Hz for the three groups were not statistically differentiated by Bekesy audiometry.

At 500 Hz (Table 10), the Bekesy mean thresholds for Group A were always larger than the means of groups B and C but there were also differences between groups B and C. These significant group differences (Table 8) occurred at the .01 level for both the continuous and the interrupted in the right ear and at the .05 level for the interrupted in the left ear. The left and right ear means never differed by more than 5 dB. In regard to Bekesy type, the continuous and interrupted tracings were nearly identical. The group A conventional means were slightly higher than the group A Bekesy means, but the reverse occurred for groups B and C. The implication of this is not clear but, indeed, the occurrance is worth noting as it differentiates the groups.

At 750 Hz (Table 10), the mean Bekesy thresholds for group A were again consistently larger than groups B and C means. In the left ear, the differences were not significant (Table 9) but significant differences occurred at the .01 level in the right ear for the continuous and interrupted presentations. Once again, the

Table 10

For computation purposes, a threshold was recorded as a coded value of 5 dB more than the maximum output value when a subject failed to respond. At 250 Hz, NR for conventional audiometry was coded at 95 dB, 90 dB for Bekesy. At 500, 750, 1000, 2000, and 4000 Hz, NR for conventional audiometry was 115 dB and 105 dB for Bekesy. At 6000 Hz, NR for conventional was 95 dB and 100 dB for Bekesy.

	Conventional			Bekesy			
				Left		Right	
Group	Frequency	Left	Right	Continuous	Interrupted	Continuous	Interrupted
A	250	88	88	89	83	89	89
	500	108	107	105	105	104	104
	750	114	114	105	105	105	105
B	250	82	85	87	87	86	86
	500	88	98	97	93	101	99
	750	98	104	101	100	103	103
	1000	107	109	98	98	104	104
C	250	79	81	85	85	82	81
	500	93	90	97	98	92	91
	750	93	93	101	100	93	95
	1000	96	96	99	99	95	96
	2000	91	97	96	94	96	95
	4000	96	103	100	99	102	101
	6000	91	100	88	88	89	90

conventional group A threshold was larger than the Bekesy group A threshold, but the reverse occurred for groups B and C.

At 1000 Hz, only groups B and C were included. The means for the continuous and interrupted values were nearly identical throughout. Differences between ears never exceeded 6 dB. Agreement with the conventional thresholds was excellent. Only Group C, by definition, yielded responses beyond 1000 Hz. All thresholds at 2000, 4000 and 6000 Hz followed patterns similar to the results obtained at 1000 Hz.

Thus, Bekesy audiometry appears to be an effective audiometric tool for use with deaf subjects. The thresholds were generally consistent with conventional audiometry and both the left and right ears revealed comparable values. There was a tendency for the Group A conventional means to be slightly higher than the comparable Bekesy means while a reverse trend occurred for groups B and C, i.e. the Bekesy means were slightly greater than the conventional means. Groups B and C were more nearly equated in magnitude. In regard to Mekesy types, as manifested by the relation of continuous and interrupted thresholds, the audiogram configurations were almost universally Type I patterns as the continuous and interrupted tracings intertwined throughout the frequency range. There were some scattered Type II patterns but these did not occur with regularity. Indeed, only one subject had a bilateral Type II pattern and four other subjects yielded a Type II pattern in one ear and a Type I in the other.

5. <u>intensive difference-limen</u>. The arcsin transformed means for air and bone conduction at 250 Hz for the left and right ears are listed separately in Table 11 and 12 respectively. This

transformation normalized the skewed distribution of percentage means but the analyses of variance results were similar to the raw data. Table 13 illustrates the untransformed raw mean (column XI) vs the arcsin mean (column Sl) at the 5 dB increment in a one-way analysis of variance for air conduction at 250 Hz.

Table 11 and 12 reveal a progressive decrease from 5 dB to 1 dB for all three groups with both air and bone conduction. Generally, group A showed larger bone conduction percentage means while groups B and C showed larger air conduction means at 5, 3 and 2 dB. At 1 dB, all three groups had larger bone conduction means. Thus, it appears that group A subjects were more sensitive to intensitive bone conduction changes and groups B and C were more sensitive to air conduction changes except at the 1 dB increment where bone conduction elicited more responses for all three groups. The values of the right and left ears were relatively similar for groups and intensity increments (Table 11, 12).

One-way analyses of variance (Table 13) showed significant group differences for air conduction at the .01 level in both at 5, 3 and 2 dB but not at the 1 dB increment. No significant differences occurred with bone conduction (Table 14). From an inspection of the air conduction means, it appears that group A was consistently smaller than groups B and C. It is also pertinent that at 1 dB, groups B and C (the partially deaf groups) yielded responses comparable to group A (the cutile group) at 5, 3 and 2 dB. Thus, 1 dB where the intensity change was not discernable, the partially deaf group performed similar to the cutile group. Further support of this observation was gleaned

Table 11

Intensity difference-limen means for air and bone conduction at four intensity incremental levels for the three groups at 250 Hz in the left ear. The values are given in the arcsin transformation.

Group A
(N = 18)

Intensity increments in dB

	5	3	2	1	Total
Air	.80	.41	.30	.09	.40
Bone	2.06	1.46	.82	.33	1.17
Total	1.43	.94	.56	.21	.78

Group B
(N = 6)

	5	3	2	1	Total
Air	3.03	2.24	1.43	.56	1.82
Bone	2.06	1.99	1.71	1.03	1.84
Total	2.83	2.12	1.57	.80	1.83

Group C
(N = 8)

	5	3	2	1	Total
Air	2.49	1.73	.96	.20	1.34
Bone	1.96	1.53	.87	.28	1.16
Total	2.23	1.63	.91	.24	1.25

Total
(N = 32)

	5	3	2	1	Total
Air	1.64	1.08	.68	.20	.90
Bone	2.14	1.58	1.00	.45	1.29
Total	1.89	1.33	.84	.32	

Table 12

Summary of one-way analyses of variance at 500 Hz for the parameters of groups, conventional vs Bekesy audiometry for continuous and interrupted presentations at the regular and plus 20 dB Bekesy calubrations re: left and right ears.

Left

Group	Conventional Threshold	Bekesy Regular		Bekesy +20 dB	
		Continuous	Interrupted	Continuous	Interrupted
A (18)	108.3	104.7	104.7	107.5	101.9
B (6)	88.3	96.7	92.5	75.0	71.7
C (8)	92.5	96.9	97.5	83.1	84.4
MSb	1252.1	248.1	388.2	3168.7	2362.7
MSw	66.7	88.1	78.0	393.4	352.1
df	2,29	2,29	2,29	2,29	2,29
F	**18.8	2.8	*5.0	**8.1	**6.7

Right

A (14)	107.1	104.3	104.3	108.2	105.7
B (7)	97.9	100.7	99.3	82.9	82.1
C (11)	90.0	92.3	91.4	73.2	72.7
MSb	913.4	452.5	515.6	4050.3	3575.8
MSw	101.0	77.0	81.7	320.2	317.4
df	2,29	2,29	2,29	2,29	2,29
F	**9.1	**5.9	**6.3	**12.6	**11.3

* = .05 level of confidence
** = .01 level of confidence

Table 13

Summary of one-way analyses of variance of difference-limen AC thresholds at 250 Hz for the left and right ears. The values are given in the arcsin transformation.

Left

		Intensity increment in dB			
Groups		5	3	2	1
	+X1	*S1			
A (18)	(2.6)	0.8	0.4	0.3	0.1
B (6)	(9.8)	3.0	2.2	1.4	.6
C (8)	(8.1)	2.5	1.7	1.0	.2
MSb	(161.4)	15.0	9.8	3.3	.5
MSw	(11.4)	1.1	.5	.5	.2
df	2,29	2,29	2,29	2,29	2,29
F	**(14.2)	**13.8	**20.0	**6.9	2.5

Right

	Intensity increment in dB			
Groups	5	3	2	1
A (14)	0.5	0.3	0.2	.1
B (7)	3.0	2.3	1.1	.5
C (11)	2.5	1.5	1.1	.3
MSb	20.3	10.4	3.6	.4
MSw	.8	.6	.3	.3
df	2,29	2,29	2,29	2,29
F	**24.7	**18.1	**12.6	1.4

+Untransformed

*Arcsin transformed

** = .01 level of confidence

Table 14

Summary of one-way analyses of variance of intensity difference-limen BC thresholds at 250 Hz for the left and right ears. The values are given in the arcsin transformation.

Left

	Intensity increment in dB			
Groups	5	3	2	1
A (18)	2.1	1.5	.8	.3
B (6)	2.6	2.0	1.7	1.0
C (8)	2.0	1.5	.9	.3
MSb	.9	.6	1.9	1.3
MSw	2.1	1.5	1.0	.5
df	2,29	2,29	2,29	2,29
F	.4	.4	1.9	2.7

Right

	Intensity increment in dB			
Groups	5	3	2	1
A (14)	1.9	1.2	.6	.1
B (7)	1.6	1.6	1.2	.6
C (11)	1.9	1.6	1.1	.5
MSb	.2	.5	1.3	.9
MSw	2.2	1.7	.8	.4
df	2,29	2,29	2,29	2,29
F	.1	.3	1.5	2.2

from the statistical comparison on the air and bone values for the left and right ears (Tables 15 and 16) group A had significant matched *t* differences at the 5, 3 and 2 dB increments in both the left and right ears. Significant differences did not occur with groups B and C in the left ear (Table 14) but occurred at the .05 level for groups B and C in the right ear.

The 500 Hz arcsin air and bone conduction means for the left and right ears are listed in Tables 17 and 18, respectively. The values show progressive decreases from 5 dB to 1 dB increments for all three groups with both air and bone conduction. Air values at 500 Hz were higher than the bone values for all three groups at each intensity increment for increments pooled. Left and right ears were very similar for air and bone with each group and matched *t* tests revealed no significant differences.

One-way analyses of variance for air conduction (Table 19) showed statistically significant (.01 level) group mean differences at intensity increments 5, 3 and 2 dB but not at 1 dB. This paralleled the results of the 250 Hz air conduction analyses. The 500 Hz bone conduction values (Table 20) were also similar to the 250 Hz values for the right ear as there was no statistical significant group differences but the left ear had significant group differences (.05) at the 3 and 2 dB intensity increments. These differences seemed attributable to a skewed group B as groups A and C had fairly close means. Left and right ear differences were not statistically different at any of the four intensities; thus, the two ears were essentially the same.

Matched *t* test comparisons of air vs bone (Tables 15, 16) at 500 Hz clearly showed significantly larger (.01 level) air

Table 15

Matched *t* comparisons of air vs bone intensity difference-limens for the left ears of Groups A, B and C at 250 and 500 Hz. The values are expressed in the arcsin transformation.

Group			Air Mean	Bone Mean	Matched *t*	df
A	250 (N=18)	5	.8	2.1	**-3.3	17
		3	.4	1.5	**-4.3	17
		2	.3	.8	*-2.2	17
		1	.1	.3	-1.7	17
	500 (N=18)	5	.7	.2	*2.2	17
		3	.6	.1	*2.0	17
		2	.3	.1	1.1	17
		1	.1	.1	.5	17
B	250 (N=6)	5	3.0	2.6	1.0	5
		3	2.2	2.0	.5	5
		2	1.4	1.7	-.5	5
		1	.6	1.0	-1.0	5
	500 (N=6)	5	3.1	1.6	*2.2	5
		3	2.6	1.3	1.6	5
		2	1.5	.8	1.5	5
		1	.4	.2	.8	5
C	250 (N=8)	5	2.5	2.0	1.1	7
		3	1.7	1.5	.5	7
		2	1.0	.9	.2	7
		1	.2	.3	-.3	7
	500 (N=8)	5	2.7	.7	**3.7	7
		3	2.2	.4	**5.6	7
		2	1.0	.3	**3.6	7
		1	.3	.1	1.5	7

* = .05 level of confidence
** = .01 level of confidence

Table 16

Matched t comparison of air vs bone intensity difference-limen for the right ears of Groups A, B and C at 250 and 500 Hz. The values are expressed in the arcsin transformation.

Group			Air Mean	Bone Mean	Matched t	df
A	250 (N=14)	5	.5	1.9	**-3.4	13
		3	.3	1.2	**-3.3	13
		2	.2	.6	*-1.8	13
		1	.1	.1	.1	13
	500 (N=14)	5	.7	.2	1.5	13
		3	.4	.1	1.3	13
		2	.3	.1	1.4	13
		1	.1	.0	1.0	13
B	250 (N=7)	5	3.0	1.6	*2.2	6
		3	2.3	1.6	1.1	6
		2	1.1	1.2	-.2	6
		1	.5	.6	-.2	6
	500 (N=7)	5	3.1	.9	**3.9	6
		3	2.3	.5	**4.0	6
		2	1.1	.4	*2.5	6
		1	.2	.0	1.0	6
C	250 (N=11)	5	2.5	1.9	*1.8	10
		3	1.5	1.6	-.2	10
		2	1.1	1.1	.2	10
		1	.3	.5	-.8	10
	500 (N=11)	5	2.8	.8	**4.3	10
		3	1.9	.3	**6.0	10
		2	1.1	.2	**4.5	10
		1	.4	.1	*1.8	10

* = .05 level of confidence.
** = .01 level of confidence.

Table 17

Intensity difference-limen means for air and bone conduction at four intensity incremental levels with the three groups at 500 Hz in the left ear. The values are expressed in the arcsin transformation.

Group A
(N = 18)
Intensity increments in dB

	5	3	2	1	Total
Air	.75	.57	.35	.10	.44
Bone	.17	.11	.10	.05	.11
Total	.46	.34	.22	.08	.27

Group B
(N = 6)

	5	3	2	1	Total
Air	3.14	2.60	1.50	.42	1.92
Bone	1.57	1.26	.83	.15	.95
Total	2.36	1.93	1.16	.29	1.43

Group C
(N = 8)

	5	3	2	1	Total
Air	2.68	2.17	.96	.29	1.53
Bone	.70	.42	.29	.08	.37
Total	1.69	1.30	.62	.18	.95

Total
(N = 32)

	5	3	2	1	Total
Air	1.68	1.35	.72	.21	.99
Bone	.57	.40	.28	.08	.33
Total	1.12	.88	.50	.14	

Table 18

Intensity difference-limen means for air and bone conduction at four intensity incremental levels with the three groups at 500 Hz in the right ear. The values are expressed in the arcsin transformation.

Group A
(N = 14)

Intensity increments in dB

	5	3	2	1	Total
Air	.67	.45	.32	.08	.38
Bone	.22	.13	.10	.05	.12
Total	.45	.29	.21	.06	.25

Group B
(N = 7)

	5	3	2	1	Total
Air	3.14	2.34	1.14	.17	1.70
Bone	.90	.54	.36	.00	.45
Total	2.02	1.44	.75	.08	1.07

Group C
(N = 11)

	5	3	2	1	Total
Air	2.79	1.87	1.11	.43	1.55
Bone	.80	.34	.20	.06	.35
Total	1.79	1.11	.66	.24	.95

Total
(N - 32)

	5	3	2	1	Total
Air	1.94	1.35	.77	.22	1.07
Bone	.57	.29	.19	.04	.27
Total	1.25	.82	.48	.13	

Table 19

Summary of one-way analysis of variance of difference-limen air conduction thresholds at 500 Hz for the left and right ears. The values are expressed in the arcsin transformation.

Left

	Intensity increment in dB			
Groups	5	3	2	1
A (18)	.7	.6	.3	.1
B (6)	3.1	2.6	1.5	.4
C (8)	2.7	2.2	1.0	.3
MSb	18.3	12.8	3.3	.3
MSw	1.0	.8	.6	.2
df	2,29	2,29	2,29	2,29
F	**17.4	**16.8	**5.8	1.3

Right

	Intensity increment in dB			
Groups	5	3	2	1
A (14)	.7	.4	.3	.1
B (7)	3.1	2.3	1.1	.2
C (11)	2.8	1.9	1.1	.4
MSb	20.2	10.6	2.5	.4
MSw	.9	.6	.3	.2
df	2,29	2,29	2,29	2,29
F	**22.7	**16.3	**8.4	1.7

** = .01 level of confidence.

Table 20

Summary of one-way analysis of variance of difference-limen bone conduction thresholds at 500 Hz for the left and right ears. The values are expressed in the arcsin transformation.

Left

	Intensity increment in dB			
Groups	5	3	2	1
A (18)	.2	.1	.1	.1
B (6)	1.6	1.3	.8	.2
C (8)	.7	.4	.3	.1
MSb	4.5	3.0	1.2	
MSw	1.2	.6	.3	.06
df	2,29	2,29	2,29	2,29
F	*3.6	*4.6	*3.6	.36

Right

	Intensity increment in dB			
Group	5	3	2	1
A (14)	.2	.1	.1	.0
B (7)	.9	.5	.4	.0
C (1)	.8	.3	.2	.1
MSb	1.5	.4	.2	.01
MSw	1.5	.4	.2	.03
df	2,29	2,29	2,29	2,29
F	1.0	.9	.7	.29

* = .05 level of confidence

values for group C at 5, 3 and 2 dB and even at 1 dB at the .05 level in the right ear. This occurred with less regularity with group B and only on two occasions in the left ear with group A. Thus, group C was differentiated with higher air conduction difference-limen scores at 500 Hz. The other two group values were fragmentary and inconclusive.

6. localization in a minimum-audible-field (MAF). Each subject was classified into group A, B or C on the basis of the better ear (Table 3); the contention was that functional performance is more closely related to the integrity of the better ear.

The raw data percentages of the correct subject localizations in a sound field were transformed to arcsin values. The analysis of variance (Table 21) showed that group values were significantly different (.01 level) at both the 250 Hz and 500 Hz parameters. Inspection of the means suggested that the C values were relatively comparable at 250 and 500 Hz. Thus, this particular procedure provided a discerning test to differentiate between the cutile subjects (group A) and the deaf subjects with some auditory reserve (groups B, C). Here was additional support that audiograms with responses at 1000 Hz may have valid hearing reserve.

A matched t test between the values of 250 Hz and 500 Hz (Table 22) for the three groups showed the values at 250 Hz were significantly better (.05 level) for groups B and C but not for group A. These data furnished additional evidence that groups B and C were functionally similar and different than group A.

Table 21

Summary of one-way analysis of variance for groups A, B and C localization responses in a minimum audible field at 250 Hz and 500 Hz. The values are given in the arcsin transformations.

+Group	250	500
A (N = 12)	1.38	.90
B (N = 6)	2.65	1.81
C(N = 14)	2.33	2.14
MSb	4.32	5.08
MSw	.38	.38
df	2, 29	2, 29
F	**11.34	**13.28

+Subjects were placed in groups A, B or C on the basis of the better ear.

** = .01 level of confidence.

Table 22

Match t-test for localization at 250 Hz and 500 Hz for groups A, B and C in a minimum audible field. The values are given in the arcsin transformations.

+Group	250	500	Matched t	df
A	1.38	.90	2.08	11
B	2.65	1.81	*3.27	5
C	2.33	2.14	*2.35	13

+ Subjects were placed in groups A, B or C on the basis of the better ear.

* = .05 level of confidence.

7. <u>monofrequency-bifrequency identification in a minimum-audible-field</u>. Each subject was classified into one of the three groups on the basis of his better ear (Table 23) as described for the localization procedure. Responses were the percentages of correct identifications of the 250 Hz tone being presented alone, the 500 tone being presented or the presence of these two tones simultaneously in the sound field.

Group differences were significant at the .01 level (Table 23). Here, too, t tests gave statistical support that groups B and C were functionally similar. It appears that Group A differed from the other two groups. This is construed as further statistical evidence that groups B and C functionally mainifested hearing reserve and the cutile group A subjects were audiologically differentiated with this sound field test procedure. Thus, another sound field procedure appears to differentiate hearing and nonhearing responses.

8. <u>tone decay</u>. The extremely narrow and small range of responses precluded any conventional interpretation from a parametric statistical analysis. Subsequently, contingency tables were used to review the tone decay data. (Tables 24-27). Each ear was classified independently into one of the three groups (Table 3).

Tone decay shifts never exceeded 10 dB so the contingency tables were established for 0, 5 and 10 dB shifts. Group A never showed any tone decay shifts for air conduction (Table 24). There were some shifts for groups B and C, but these were fragmentary and did not reach chi square significance. Bone conduction almost never showed tone decay shifts. Thus, at 250

Table 23

Summary of one-way analysis of variance for groups A, B and C monofrequency and bifrequency identification responses of 250 Hz and 500 Hz in a minimum audible field. The values are given in the arcsin transformations.

+Group	arcsin
A (N = 12)	1.26
B (N = 6)	2.01
C (N = 14)	2.14
MSb	2.68
MSw	.23
df	2,29
F	**11.47

+Subjects were placed in groups A, B or C on the basis of the better ear.

** = .01 level of confidence.

Table 24

Tone decay threshold shift contingency table of responses in total and percentage values at 250 Hz for air conduction.

Group		LEFT				RIGHT			
		0	5	10	Total	0	5	10	Total
A	%	100	0	0	56	100	0	0	44
	N	18	0	0	18	14	0	0	14
B	%	83	17	0	19	71	29	0	22
	N	5	1	0	6	5	2	0	7
C	%	88	13	0	25	55	27	18	34
	N	7	1	0	8	6	3	2	11
Total	%	94	6	0		78	16	2	
	N	30	2	0	32	25	5	2	32

Table 25

Tone decay threshold shift contingency table of responses in total and percentage values at 250 Hz for bone conduction.

		LEFT				RIGHT			
Group		0	5	10	Total	0	5	10	Total
A	%	100	0	0	56	100	0	0	44
	N	18	0	0	18	14	0	0	14
B	%	100	0	0	19	100	0	0	22
	N	6	0	0	6	7	0	0	7
C	%	100	0	0	25	73	27	0	34
	N	8	0	0	8	8	3	0	11
Total	%	100	0	0		91	9	0	
	N	32	0	0	32	29	3	0	32

Hz, the tone decay test was not an effective audiologic tool with deaf subjects.

At 500 Hz, there were one or two instances of a 5 dB shift for group A for air conduction (Table 26). However, groups B and C showed more impressive 5 dB air conduction shifts which often reached chi square significance as opposed to the 250 Hz frequency. Bone conduction (Table 27) tone decay was inconsequential. Thus, there were instances where 5 dB tone decay shifts differentiated the cutile group from the other two groups.

9. speech reception thresholds SRT. Only in a few isolated instances were any SRT scores elicited. Three subjects gave responses in excess of 90 dB, two of whom gave thresholds bilaterally and the other in only one ear. One additional subject gave bilateral responses, i.e., 70 dB and 65 dB for the left and right ears. The SRT values were not of any pertinence in differentiating among the groups or even intra-subject differences.

10. intelligibility scores. There was less success in obtaining any scores with respect to the phonetically balanced words. This sample of subjects had particular difficulty with speech material; only one student was able to give a score for each ear.

Table 26

Tone decay threshold shift contingency table of responses in total and percentage values at 500 Hz for air conduction.

		LEFT				RIGHT			
Group		0	5	10	Total	0	5	10	Total
A	%	94	6	0	56	93	07	0	44
	N	17	1	0	18	13	1	0	14
B	%	83	17	0	19	43	43	14	22
	N	5	1	0	6	3	3	1	7
C	%	63	38	0	25	46	55	0	34
	N	5	3	0	8	5	6	0	11
Total	%	84	16	0		66	31	03	
	N	27	5	0	32	21	10	1	32

Table 27

Tone decay threshold shift contingency table of responses in total and percentage values at 500 Hz for bone conduction.

		LEFT				RIGHT			
Group		0	5	10	Total	0	5	10	Total
A	%	100	0	0	56	100	0	0	44
	N	18	0	0	18	14	0	0	14
B	%	83	17	0	19	100	0	0	22
	N	5	1	0	6	7	0	0	7
C	%	88	13	0	25	91	09	0	34
	N	7	1	0	8	10	1	0	11
Total	%	94	06	0		97	03	0	
	N	30	2	0		31	1	0	32

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions. The conclusions were as follows:

1. pure tone air conduction.

   a. Threshold means decreased progressively from group A to group B to group C at frequencies 250, 500, 750 Hz in both the right ear and left ear. On most occasions, the differences reached statistical significance.

   b. Group A, the cutile subjects with no demonstrable auditory reserve, had conspicuously different threshold means than groups B and C with ostensible hearing. In this regard, groups B and C seemed comparable.

   c. There was a high percentage of group A no response designations, which never occurred with groups B and C. Thus, groups B and C were again functionally similar to each other.

   d. Agreement between ears was nearly universal throughout the study and statistically confirmed, in most instances.

2. pure tone mastoid and frontal placement bone conduction.

   a. Groups were undifferentiated by bone conduction; there was a narrow range of responses and a greater number of no response designations particularly at 500 Hz. One trend showed that the no response ratios were higher for group A with the frontal placement but the reverse occasionally occurred with groups B and C.

b. Frontal placement of the bone oscillator generally precipitated 5 dB higher thresholds than with mastoid placement but these did not follow any pattern relative to the frequency or group parameters. Thus, bone conduction audiometry was not an effective procedure to differentiate among groups.

c. At frequencies 250, 500, 750 Hz, the two ears had nearly identical thresholds for the several variables tested.

This occurred for each of the three groups.

3. occlusion.

a. Occluded bone conduction thresholds were undifferentiated from the unoccluded thresholds and subsequently could not be used to differentiate hearing from non hearing deaf subjects.

Laterality was not demonstrated in any predictable trend or with any consistency.

4. Bekesy audiometry.

a. Threshold means decreased progressively from group A to group B and group C at frequencies 250, 500 and 750 Hz, in both the left and right ears.

b. Bekesy audiometry is another way to test deaf children as the mean thresholds were similar to those obtained by the conventional manner of tone presentation. In several instances, the group A thresholds were better with the Bekesy method while groups B and C had the reverse, i.e., better conventional thresholds.

c. Generally, both ears were similar with the continuous and interrupted methods of tone presentation although occasional departures occurred.

d. Type I Bekesy patterns were nearly universal throughout as the continuous and interrupted tracings were comparable.

e. Bekesy audiometry did not provide any different diagnostic audiologic information than conventional air conduction to distinguish between the cutile deaf and those with some valid auditory reserve.

5. <u>Intensitive difference-limen</u>.

a. Response values, expressed in percentages, decreased progressively from intensity increments, 5, 3, 2 and 1 dB for air and bone conduction with each of the three groups.

b. Agreement between ears was nearly universal throughout and statistically confirmed in most instances.

c. Group A, the cutile subjects with no demonstrable auditory reserve, had statistically significant better bone conduction scores while groups B and C had significantly better air conduction scores. Thus, this procedure appeared helpful in differentiating the cutile group from the hearing groups B and C: Groups B and C were usually undifferentiated from each other.

d. Intensity increments 5, 4, 3 dB precipitated significant group mean differences but not the 1 dB increment. This held true for both air and bone conduction for each of the three groups and both ears.

6. <u>Localization in a minimum-audible-field</u>.

   a. Localization of the 250 Hz and the 500 Hz pure tones in a sound-field showed the cutile group was statistically differentiated from the B and C groups. Thus, this procedure was a helpful audiologic adjunct to differentiate between the cutile and the partially deaf subjects. Groups B and C were undifferentiated in this respect.

   b. When the 250 Hz means were compared to the 500 Hz means, group A did not manifest a significant mean differences, but groups B and C showed statistically significant differences. Thus group A was differentiated from the other two groups with this comparison.

7. <u>Monofrequency-bifrequency identification in a minimum-audible-field</u>.

   a. The group A mean was statistically differentiated with this procedure from groups B and C which were not statistically differentiated. Thus, this procedure provided helpful audiologic information to differentiate the hearing from the non-hearing deaf subjects.

8. Tone decay.

   a. Air conduction tone decay at 250 Hz and bone conduction tone decay at 250 Hz and 500 Hz did not reveal any statistically demonstrable shifts for groups A, B and C. However, for air conduction at 500 Hz, the shifts reached significance for groups B and C and in one instance for group A.

   b. Tone decay is a possible audiometric technique to differentiate between the cutile and the partially hearing deaf subject. Perhaps, there is some pertinent diagnostic information here relative to cochlear and retrocochlear pathology. Generally, these data were inconclusive and warrant further investigation.

9. Speech tests.

   a. Speech reception thresholds were fragmentary and subsequently did not differentiate among the groups.

B. Recommendations

1. This study should be expanded to include a more extensive population and a wider variety of cases. The speech scores, in particular, may reflect the sampling of only one school for the deaf.

2. Procedures that provided audiological information to differentiate between the cutile and the partially deaf subjects should be refined and standardized as a substantial audiologic tool.

3. Deaf subjects with reliable thresholds for air conduction at 1000 Hz can be construed to have valid auditory reserve

and probably do not belong in the cutile category. The incidence of bilateral cutile ears needs to be established.

4. Careful exploration should investigate the effects of intensive vibrotactile sensory experiences with the cutile children. Along parallel lines, low frequency transposition and alternate ways to exploit available sensory experiences with the cutile children. Along alternate ways to exploit available perceptions through intact sensory systems must be emphasized.
5. Speech reception thresholds and discrimination scores of young deaf children should be longitudinally reassessed relative to the cutile and partially hearing categorizations to determine the direct effects of auditory training and speech therapy. This is crucial for the younger children where speech and language readiness inherently enhances oral communication. In other words, the inability to demonstrate receptive communicative differences between the cutile and partially deaf groups in teenage children does not preclude demonstrative differences in younger children with the appropriate training. During the formative years, auditory reserve should be exploited to its maximum with vibrotactile and visual reinforcements employed in varying proportions.
6. A similar orientation should be directed to the scholastic achievement level patterns of these children for improved and more efficient use of the modalities that are most functional. In this respect, an experimental program to

explore academic and rehabilitative techniques should be more clearly defined for the cutile and partially deaf children.

7. Dissemination of the information now available from this and other studies is essential to alert audiologists, teachers of the deaf, speech and language therapists, otologists, etc., that audiograms do not always represent valid auditory reserve. Realistic awareness of the hearing function should put constraints on the curricula and goals.

8. Hearing aid manufacturers should consider notations on the audiometers' attenuators beyond specified output levels at frequencies 125, 250, 500 and 750 Hz for both air and bone conduction where cutile mediation occurs.

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